Movements of Golden Perch *Macquaria ambigua* (Richardson) in the mid Murray and lower Murrumbidgee Rivers (New South Wales) with notes on other species

L.C. Llewellyn

Curlew Biological Services, P.O. Box 67, Pacific Palms, NSW 2428.

E-mail leighton@activ8.net.au

ABSTRACT

A tagging and recapture program was carried out between 1959 and 1970 on large freshwater fish species in the Murrumbidgee and Murray Rivers to determine the patterns of their movement. Tagging was carried out at four main sites Stoney Crossing, Hattah, Hay and Narrandera. At the time internal body tags were found to be the most reliable method of tagging. Adequate numbers of Golden Perch, *Macquaria ambigua,* and low numbers of Murray Cod *Maccullochella peelii peelii* and Silver Perch *Bidyanus bidyanus* were recaptured. It is concluded that up - and downstream movement of *M. ambigua* from these sites varied. The western two sites at Stoney Crossing and Hattah on the Murray River showed a marked net upstream movement; movement from Hay on the Murrumbidgee showed dispersal both up and downstream, while movement from Narrandera showed a net downstream movement. Within the size range sampled 309-563mm, the larger fish moved significantly less than the smaller fish; when split into upstream and downstream movement, this was only significant for upstream movement.

*B. Bidy*anus, tagged in the upper two sites, showed a net downstream movement from Narrandera with a single upstream movement from Hay. *M. peelii peelii* showed only minor movements (up to 141 km) up and downstream from Narrandera, with only one long distance movement from Balranald to Gundagai. Net downstream stream movement of *M. ambigua* declined as one moved downstream closer to the mouth of the Murray River.

Key words: Fish movements in Murray-Darling Basin. *Macquaria ambigua* movement patterns

DOI: http://dx.doi.org/10.7882/AZ.2013.014

Introduction

Tagging programs have been the main source of reliable data on movement of inland native fish. At the time of this study (1959-1970) acoustic and radio tags were not available and internal or external plastic tags were used on which were printed return information. The localities at the time of release and recapture provided information on the minimum distance travelled and often the speed of movement. Recoveries of tagged fish at that time had been limited, and thus understanding of movement patterns had relied on relatively few records.

This extensive joint New South Wales, Victoria Fisheries Department tagging program (1959 and 1970) in the mid Murray and lower Murrumbidgee Rivers in NSW waters, was stepped up in 1964 in conjunction with a research program looking into the ageing methods and growth of inland fish in the wild. The data used in this paper is also a key component of the papers by Llewellyn (2008) on growth of Golden perch *Macquaria ambigua* and Llewellyn (2011) on length weight relationships of freshwater fish of the Murray-Darling River system. The tagging methods in these studies using an internal body tag (IBT) have been described previously Llewellyn (2008).

This paper reports the final results of this tagging program on inland fish in NSW. A preliminary report on this study was published by Llewellyn (1968). Initially all large fish trapped by NSW Fisheries at Narrandera and Hay (1966-1970) were tagged (See Table 1), but as only 12 of the native Freshwater Catfish *Tandanus tandanus*, and 13 of the introduced Tench *Tinca tinca* and 6 Redfin *Perca fluviatilis* (Plate 2) were caught and no recoveries received, these three species are not considered further here. Victoria only tagged M. *ambigua* during their trapping at Hattah and Stoney Crossing between 1959 and 1964. Numerous recoveries of tagged M. *ambigua,* and less numerous recoveries of tagged Murray Cod *Maccullochella peelii peelii,* and Silver Perch, *Bidyanus bidyanus* (Plate 1), allowed for analysis of movement patterns of these three species in the mid Murray and the mid to low Murrumbidgee Rivers to be made.

One of the first tagging programs of inland fish in NSW was carried out by Stead in 1909 (cited in Reynolds 1983) in the Murrumbidgee and Edwards Rivers, but only a few recoveries were reported. In 1940, 203 M. *peelii peelii* were tagged in the Murray River at Euston weir Loch 15 from the fish ladder, but no recapture data are available (Narrandera Fisheries Centre records). Sporadic tagging was carried out by South Australian (SA) Fisheries in the early 1940's but few recaptures

Table 1. Numbers of fish tagged by locality for each year between 1959 and 1970. The localities in the area boxed were grouped as one site at Narrandera for further analysis. Numbers in brackets indicated fish that died after tagging. GP = Golden Perch, SP= Silver Perch, MC = Murray Cod.

Localities	1959	1960		1961		1963	1964	1966			1967	1968			1969			1970			
	GP	GP	MC	GP	SP	GP	GP	GP	SP	MC	GP	GP	SP	MC	GP	SP	MC	GP	SP	MC	Tot.
Euston fish ladder	-	-	-	-	-	-	-	-	-	-	-	6(1)	1	-	-	-	-	-	-	-	7(1)
Stoney Cossing (Neds Corner)	48	277	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	325
Hattah	-	175	2	-	-	328	191	-	-	-	-	-	-	-	-	-	-	-	-	-	696
Inland Fisheries Research Station	-	-	-	16	10	-	-	238(8)	342(5)	5	1	4	-	-	-	-	-	7	29(1)	26(1)	678(15)
Angel's Beach	-	-	-	-	-	-	-	37(1)	114(3)	-	-	42	29(1)	3	4	124(7)	2	3	113(6)	5	476(18)
Spencer's Beach	-	-	-	-	-	-	-	-	-	-	-	64	51(1)	3	133(7)	112(5)	9	3	99(1)	2	476(14)
Whitby's Beach	-	-	-	-	-	-	-	-	-	-	-	7	31(2)	-	3	2	-	5	102(3)	11	161(5)
Narrandera road Bridge	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	9(1)	2	14(1)
Ganmain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
Euroley	-	-	-	-	-	-	-	-	-	-	-	8	6	-	-	-	-	-	-	-	14
Toganmain	-	-	-	-	-	-	-	-	-	-	-	24	24	-	-	-	-	-	-	-	48
Hay (Pevensey Station)	-	-	-	-	-	-	-	-	-	-	-	210(6)	14	2	209(5)	18	5	-	-	-	458(11)
Balranald (Wilks Property)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	9	4	-	-	-	24
Yanga Lake	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1
Brewarrina	-	-	3	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6
Bourke	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
TOTAL	48	459	5	16	13	328	191	275(9)	456(8)	5	1	365(7)	156(4)	8	361(12)	265(12)	20	21	353(12)	46(1)	3392(65)

Golden Perch	2065	Freshwater Catfish	12
Silver Perch	1243	English Perch	6
Murray Cod	84	Tench	13
TOTAL	**3392**	**TOTAL**	**31**

GRAND TOTAL 3423

NB These numbers vary slightly from those reported for the same tagging program in Llewellyn (2008) because tagging mortalities are included here.

were recorded (Reynolds 1983). One of the largest tagging programs was carried out by Reynolds (1976; 1983) in SA where 14,333 fish (3267 *M. ambigua*) were tagged with individually numbered International Orange Floy 67C anchor tags (See Reynolds 1983 for details of tagging method), and 1276 were recaptured. This study by Reynolds provided considerable movement data on fish tagged in the Murray River in SA. Some of his data were summarised in Pusey *et al.* (2004).

From these early studies, some conclusions had been drawn in relation to the migration patterns of fish in the Murray Darling River System. It was generally accepted that the greatest movements coincide with increased water flows and flooding. Reynolds (1976; 1983) found that mature *M. ambigua* in SA migrated extensively upstream when triggered by a rise in water level at the onset of flooding. Lake (1967a, b) (also Llewellyn's *pers obs.*), noticed that fish moved into flooded areas, and noted increased activity of *M. ambigua* when spawning during spring floods. Upstream movement increased during floods which were indicated by the large numbers of fish caught in drum nets, which depend on upstream movement (Llewellyn 1968). My examination of records of fish using the Euston fish ladder, particularly during increased flows, indicated a significant movement upstream at these times.

Results from tagging programs have revealed that some fish move large distances in the inland rivers of NSW. Roughley (1961) reported that "Murray Cod *Maccullochella maquariensis* (now *M. peelii peelii*) caught at Bringagee in the Murrumbidgee River were caught at varying periods later at Narrandera 150 miles upstream". The present author reported a *M. peelii peelii* moving upstream 936 miles in 488 days (Anon. 1971), and a *M. ambigua* moving downstream 740 miles in 1,223 days. Reynolds (1983) tagged 3267 *M. ambigua* of which 704 were recaptured and found that mature *M. ambigua* migrated extensively upstream, many moving over 1000 km.

Mallen - Cooper (1994) classified *M. ambigua* as a potamodromous species and Mallen - Cooper *et al.* (1995) reported significant numbers of juvenile *M. ambigua* greater than one year old moving through Torrumbarry weir on the Murray River. Movement of mature *M. ambigua* was recorded from Lake Keepit into the Namoi and Manilla Rivers in spring at temperatures between 16 and 20°C (Battaglene 1991; Battaglene and Callanan 1991).

Advances in technology relating to the tagging and the ability to trace the movement of fish using radio telemetry since this study have been considerable. The advantages of these techniques are that each individual fish can be tracked in great detail and on a regular basis, which is not possible using the earlier techniques. However the new technology does not always provide the opportunity to obtain the size of the fish after a given time free for growth studies, unless it can be recaptured. Results using radio telemetry have confirmed that fish move considerable distances. Koehn *et al.* (2004) from radio tracking research identified the importance of downstream movement, as impedance to upstream movement of fish in the Murray River basin had received most attention in the past. In addition, Koehn (2009) using radio tracking examined habitat selection of *M. peelii peelii* in the Ovens and Murray Rivers. He found they used channel habitats in the river and preferred areas with the presence of high loadings of structural woody habitat particularly beneath overhanging vegetation where flow rates were slower close to the bank. Younger fish selected shallower habitats with greater amounts of woody habitat than adults. O'Connor *et al.* (2005), using radio-tracking, determined that *M. ambigua* in the Murray River at Nyah displayed strong home range fidelity not moving much during years of low flow, but could move long distances particularly in late spring during periods of rising water temperature and river flows, and then return to their home site. Koster *et al.* (2012) and Crook and Koster (2004) using acoustic transmitters demonstrated the inter connectivity of populations of *M. ambigua* showing movement from the Goulburn River to the Murray River and vice versa influenced by spawning and river flows. Leigh and Zampatti (2011) used radio transmitters in an attempt to provide improved management of flow dynamics and connectivity for fish population in the Chowilla Anabranch and floodplain. They found that movement patterns were complex and postulated that Golden Perch needed longitudinal physical and hydrological connectivity over at least 100km for successful breeding. Jones and Stuart (2007) studied movement and habitat selection of juvenile *M. peelii peelii* using radio tracking. They found that they had a mean daily movement of only 15m and preferred submerged woody habitats in the mainstream where depths were around 2.3m and flow rates around 0.56 $m.s^{-1}$

This study complements these more recent studies by providing movement data of large numbers of fish and an analysis of movement related to both body size and position within the river system.

Methods

Tagging of fish took place between 1958 and 1970 at four main sites. In the mid reaches of the Murray River in NSW tagging was carried out at Hattah (Colignan end of Chalka Creek) 34°35′ 142°26′ and at Stoney Crossing (5 km downstream from lock 8 near Popperwagakee Creek) 34°08′ 141°20′. In the lower Murrumbidgee River, tagging was carried out at Narrandera and upstream, approximately 34°46′ 146°35′, and at Pevensey downstream from Hay 34°33′ 144°38′. There were 5 locations at Narrandera, Narrandera River Bridge, at the Pump House of the Narrandera Fisheries Centre and on Spencer's, Angel's, and Whitby's properties upstream of the Pump House. All these sites were approximately 2 to 3 kilometres apart. For overall analysis, all Narrandera sites were lumped together, although short movements up or down stream were noted relevant to the specific site.

Fish were mainly captured during floods using drum or fyke nets, when fish were moving and feeding (Llewellyn 1968). Gill nets were used rarely in no or very low flow situations but damage to fish and fish mortalities were greater using this method. Drum nets with a diagonal mesh ≥11.0 cm were placed on steepish clay banks generally on the outside edge of a river bend, where flows were around $1 m s^{-1}$. Only fish >30 cm in length or > 500 g in weight were captured. Fish were anaesthetised before tagging using quinaldine at concentrations between 5 and 10 mg/l (see Plate 4 transfer of fish to anaesthetising pool). An Internal Body Tag (IBT) was inserted into the abdominal cavity through a ventro-lateral incision angled anteriorly, about 2.5 cm anterior to the vent (see Llewellyn, 1968; 2008). These plastic tags possessed an individual number, instructions and address details for forwarding information. The tag number, species of fish, weight to the nearest gram, total length to the nearest mm, sex where possible, locality, and date of tagging were recorded. Fish were kept out of water for the minimum length of time and were then allowed to fully recover in a holding pool before final release back into the area of river where they were caught.

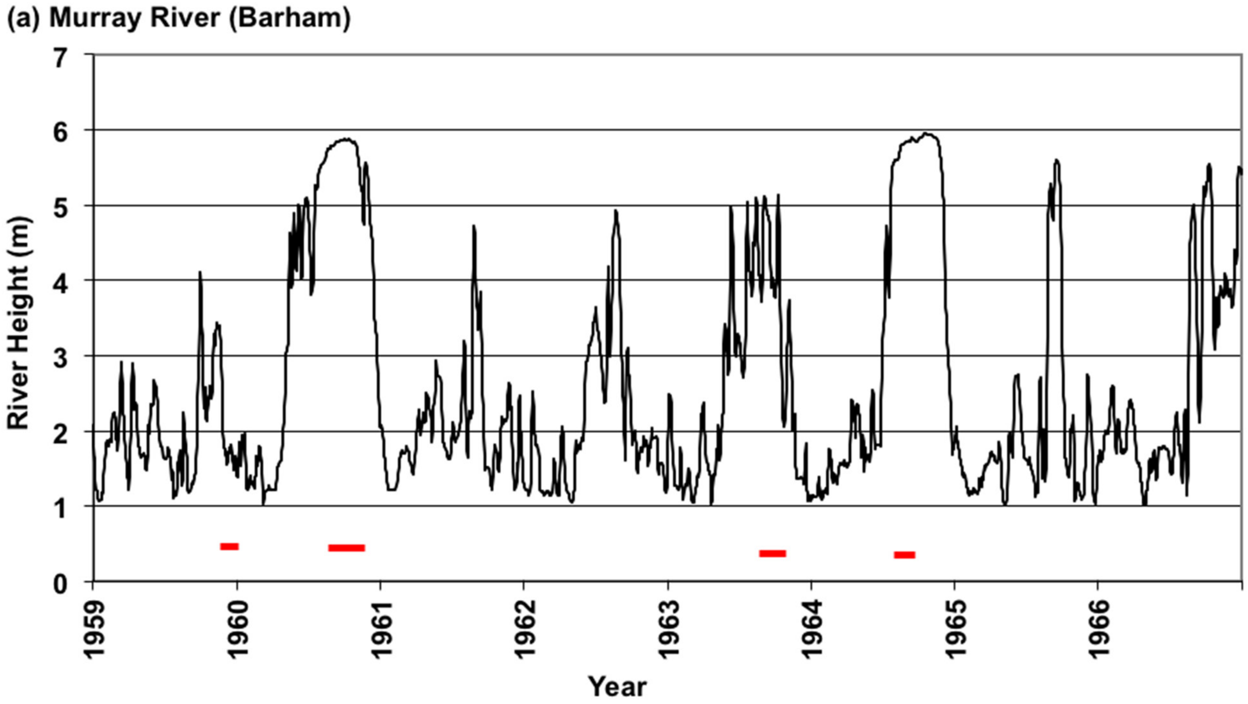
Recovery rates of tags by fishermen have already been reported (Llewellyn 2008). The site of recapture was considered to be reliably reported, and is the basis of the analysis of fish movement in this paper. The river distances travelled between the initial tag site and the recapture site were determined by measuring off 5 mile lengths of river on a map using a dividers, and multiplying the resultant mileage by 2.5. This factor was verified by measuring a number of short sections of river (Llewellyn 1968). Virtually all original data was recorded in miles, and later converted to kilometres. The distances determined represented the distances between the tagging site and recapture site on the river; however it is emphasised that fish may have moved much greater distances than this in the period before capture.

Movement patterns were mapped for *M. ambigua*, *B. bidyanus* and *M. peelii peelii* from the four major tagging sites, and these movements were analysed with respect to river heights by plotting river heights over the periods between tagging and recapture. The total length of each *M. ambigua* was plotted against the distance it moved (up and downstream) in the form of a scatter diagram. They were plotted also separately for up and downstream movements. A correlation coefficient "r" was determined for these plots.

Results

Summary of fish tagged and recovered

A total of 3392 fish (2065 *M. ambigua*, 1243 *B. bidyanus*, 84 *M. peelii peelii*,) were tagged, 2351 of which were captured and released in the Murrumbidgee River, 13 in the Darling River by the NSW Fisheries Department, and 1028 (mainly *M. ambigua*) captured and released in the Murray River by the Victorian Fisheries Department (Table 1). In the Murrumbidgee River, initial catches for tagging occurred following or during periods when short term high river level spikes were occurring, at times of year when general river flows were greatest (Fig. 1b). This was the only time they could be caught in high numbers in drum nets which relied on an upstream movement of fish (see Llewellyn 1968). In the Murray River, all fish were captured during pronounced high river flows (Fig. 1a). The different flow patterns in the Murray and Murrumbidgee Rivers are probably a result of stream regulation differences. Poor to no catches were obtained in the Murrumbidgee River in 1967 and the Murray River in 1961 and 1962 when these conditions were not met.



(a) Murray River (Barham)

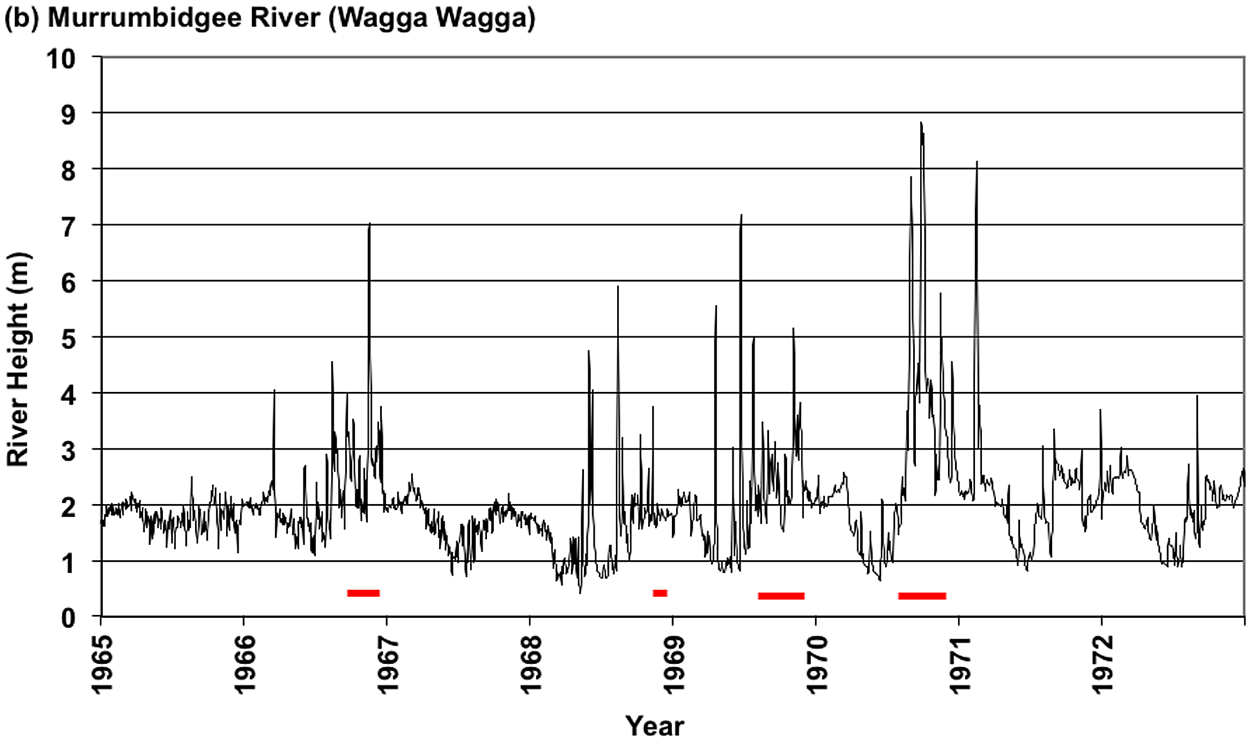

(b) Murrumbidgee River (Wagga Wagga)

Figure 1. River heights at (a) Barham on the Murray River and (b) Wagga Wagga on the Murrumbidgee River during the periods of catching fish (heavy red line). Numbers of *M. ambigua, B. bidyanus* and *M. peelii peelii* caught during those periods are shown in Table 1, 2 and 3.

Up to October 1979, 183 M. *ambigua*, 18 *B. bidyanus* and 17 M. *peelii peelii* were recaptured. At any site and for any time at tagging (see Table 2) the percentage recapture of tagged fish varied from 2.1 to 25.0% with an overall recapture of 9.1% for M. *ambigua* (Table 2), 0.8 to 5.6% with an overall recapture of 1.4% for *B. bidyanus* and 17.4 to 50.0% with an overall recapture of 20.2% for M. *peelii peelii* (Table 3) tagged at the principal tagging sites.

Table 2. Numbers of *M. ambigua* tagged, recaptured and percentage recaptured by year for the four main tagging sites. (* recaptures from other localities were Euroley 2, Euston fish ladder1, Balranald 1 and Yanga Lake 1).

Locality	Date tagged	Number tagged	Number recaptured	% recaptured
Narrandera	Nov-Dec 1966	275	32	11.6
	Sept 1967	1	1	-
	Oct-Nov 1968	117	23	19.7
	Aug-Dec 1969	140	14	10.0
	1970	21	5	23.8
	1961	16	4	25.0
Total		**570**	**79**	**13.9**
Hay	Nov 1968	210	22	10.5
	1969	209	6	2.9
Total		**419**	**28**	**6.7**
Hattah	Sept 1960	175	12	6.9
	Oct 1963	328	35	10.7
	1964	191	7	3.7
Total		**694**	**54**	**7.8**
Stoney Crossing	Dec 1959	48	1	2.1
	Sept 1960	227	16	7.0
Total		**275**	**17**	**6.2**
Total for 4 sites	**Dec 59-1970**	**1958**	**178**	**9.1**
Other localities see Table 1	1960-69	56	5*	8.9
Grand total		**2014**	**183**	**9.1**

Known mortality from tagging overall was 1.9% (65 out of 3392 tagged) (Table 1). This included fish which did not recover from the holding bath, possibly as a result of catch injury or the tagging or anaesthetising process, as well as fish that were found downstream over the following few days.

Movement of Most recaptured fish had moved at least some distance as shown in Fig. 2 for the four main tagging sites. Both mean and cumulative upstream and downstream movements from the tagging sites were recorded (Table 4). Fish originally tagged at Stoney Crossing moved a maximum upstream distance of 1075 km and mean upstream distance of 209 km (range 4-1075 km), while Hattah fish moved up to1097 km and a mean upstream movement of 397 km (range 8-1097); in both cases these upstream distances were greater than downstream movement (Fig. 2 and Table 4). The maximum downstream movement was recorded from Narrandera tagged fish with a distance of 1131 km and mean downstream movement of 102 km (range 2-1131 km), A Hay tagged fish also moved 962 km downstream and the mean downstream movement was 174 km (range 4-962 km) (Fig. 2 and Table 4). In both these cases mean downstream distances were greater than mean upstream distances, although in the case of Hay total upstream distance was greater than the total downstream movement. When upstream movements and downstream movements were pooled by adding upstream distances to negative downstream distances the same trends were evident. The resulting cumulative movement showed a marked downstream movement of fish from Narrandera of -1397 km and a mean distance for all recaptured fish from this site of -18 km (ie downstream). Hattah on the other hand showed a cumulative distance upstream of 11,310 km with a mean upstream distance of 217 km and Stoney Crossing with a cumulative upstream distance of 3118 km and a mean of 183 km. Hay was intermediary with a cumulative upstream movement of 217 km and a mean upstream movement of 8 km (Table 4).

Most fish tagged at Stoney Crossing below the Murray and Darling Rivers junction were recovered relatively close to the tagging site as was the case for other sites. Most fish from Hattah were recovered between Mildura and Euston. Fish marked at Hay showed a general dispersion along the Murrumbidgee River between Maude in the west and Darlington Point in the east, and most fish recaptured from the Narrandera tagging were recovered between Wagga 217 km upstream and Carathool 300 km downstream (Fig. 2).

Two fish from Stoney Crossing had travelled long distances up the Murray and one had gone up the Darling to

Table 3. Numbers of *B. bidyanus* and *M. peelii peelii* tagged, recaptured and percentage recaptured by year for the four main tagging sites (* one *B. bidyanus* recaptured from tagging at Brewarrina on the Darling River and ** two *M. peelii peelii* recaptured one from tagging at Balranald and one at Brewarrina).

Locality	Date tagged	Number tagged	Number recaptured	% recaptured
SilverPerch				
Narrandera	1961	10	-	-
	Nov-Dec 1966	456	5	1.1
	Oct-Nov 1968	111	5	4.5
	Aug-Nov 1969	238	2	0.8
	Oct-Nov 1970	352	4	1.1
Total		**1167**	**16**	**1.4**
Hay	Nov 1968	14	-	-
	Nov 1969	18	1	5.6
Total		**32**	**1**	**3.1**
Other localities		44	1*	2.3
Grand total		**1243**	**18**	**1.4**
Murray Cod				
Narrandera	Nov-Dec 1966	5	-	-
	Nov 1968	6	2	33.3
	Aug-Nov 1969	11	4	36.4
	Oct-Nov 1970	46	8	17.4
Total		**68**	**14**	**20.6**
Hay	Nov 1968	2	-	-
	Nov 1969	5	-	-
Total		**7**	**-**	**-**
Hattah		2	1	50.0
Other localities		7	2**	28.6
Grand total		**84**	**17**	**20.2**

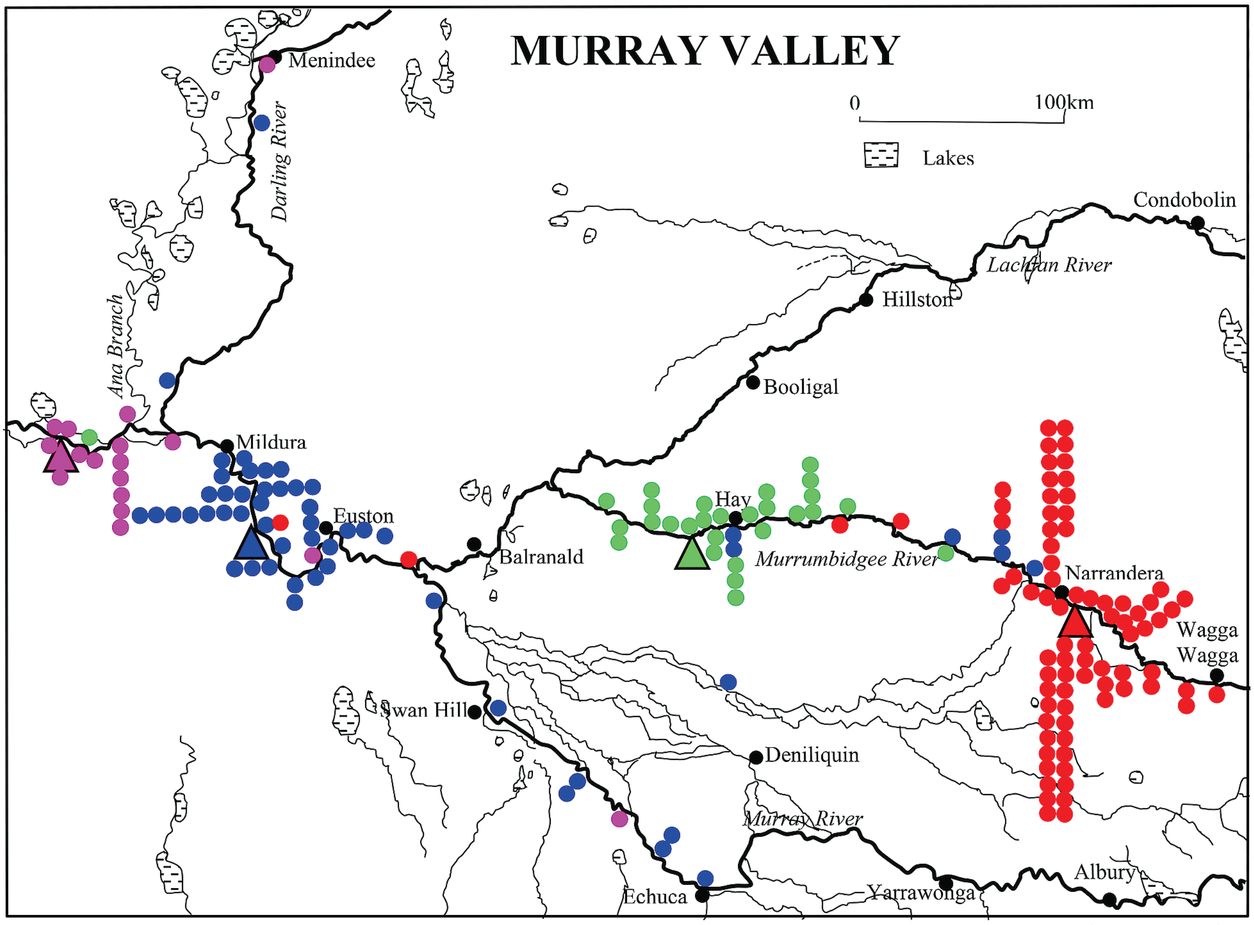


Figure 2. Movement of *M. ambigua* showing initial capture sites at Stoney Crossing (Neds Corner)▲, Hattah▲, Hay▲ and Narrandera▲, and respective recapture sites ● ● ● ●

Table 4. Number of recaptured *M. ambigua*, mean distance moved in kilometers, total distance moved for all fish summed, maximum distance moved by an individual fish, for upstream and downstream movement. Accumulated movement includes all distances for upstream and downstream added together and assumes downstream movement is negative. Numbers in brackets were not used because fish moved up and downstream from one river system into another.

	Upstream movement				Downstream movement				No movement	Accumulated movement		
Locality of tagging	Number recaptured	Distance moved (km)			Number recaptured	Distance moved (km)			Number recaptured	Total numbers recapt.	Distance moved km)	
		Mean	Total	Maximum		Mean	Total	Maximum			Total	Mean
Narrandera	35	53	1861	211	32	102	3258	1131	12	79	-1397	-18
Hay	18	89	1610	334	8	174	1393	962	2	28	217	8
Hattah	31	397	12312	1097	19	53	1002	157	2 (2)	52	11310	217
Stoney Crossing	15	209	3140	1075	2	11	22	18	0	17	3118	183

Menindee. From the Hattah site just above the Darling junction seven went long distances upstream along the Murray, six long distances up the Murrumbidgee, and one into the Wakool system. No recoveries were reported from rivers entering the Murray from the south or from the Lachlan River. Two fish had gone downstream from this site and then entered the Darling River one nearly reaching Menindee. From Hay a single fish had gone a long distance 986 km downstream to close to Stoney Crossing, and one Narrandera tagged fish was recovered just west of Balranald 580 km and one near Hattah 1094 km downstream (Fig. 2). This pattern shows a fair amount of mixing of stocks within the population in the central Murray-Darling River System, although a greater tendency for long distance movements of fish from the lower sites to move upstream and fish from the upstream sites to move downstream.

The *M. ambigua* that had travelled the maximum distance of 1131 km downstream had been free for 1225 days, while the fish that had been free the longest for 3995 days was recaptured 44km upstream.

The fastest movement was 829 km in 61 days at 13.5 km per day. Five fish recorded speeds over 10 km per day for distances between 50 and 828 km and a long distance movement from Stoney Crossing involved a fish travelling at a speed of around 6.4 km per day over 1050 km.

Movement related to river height

Significant upstream movement was often associated with large river rises (See Plate 3a,b large flood adjacent to the Narrandera Research Station). When distances travelled were plotted for the year of release at each location against days the fish were free and compared with river heights over the same period, the largest upstream movements occurred during or after large river rises. For example, individuals tagged at Hattah in Oct 1963 (Fig. 3a) were recaptured up to 1000km upstream following the significant 5m + floods a year later. Two long distance upstream movements from fish tagged at Stoney Crossing also occurred after large river rises (Fig. 4). In the case of Hay fish released in Nov 1968 most upstream movement was well below 200 km but also occurred after river rises had occurred (Fig. 5). From this site one fish had travelled downstream for 1006 km at 2.3 km per day. At Narrandera, fish during 1966, 1968 and 1969 (Fig. 6 a.b.c) showed no long upstream movements, most being below 200 km.

Movement related to individual length

The drum nets, which only caught fish moving upstream,

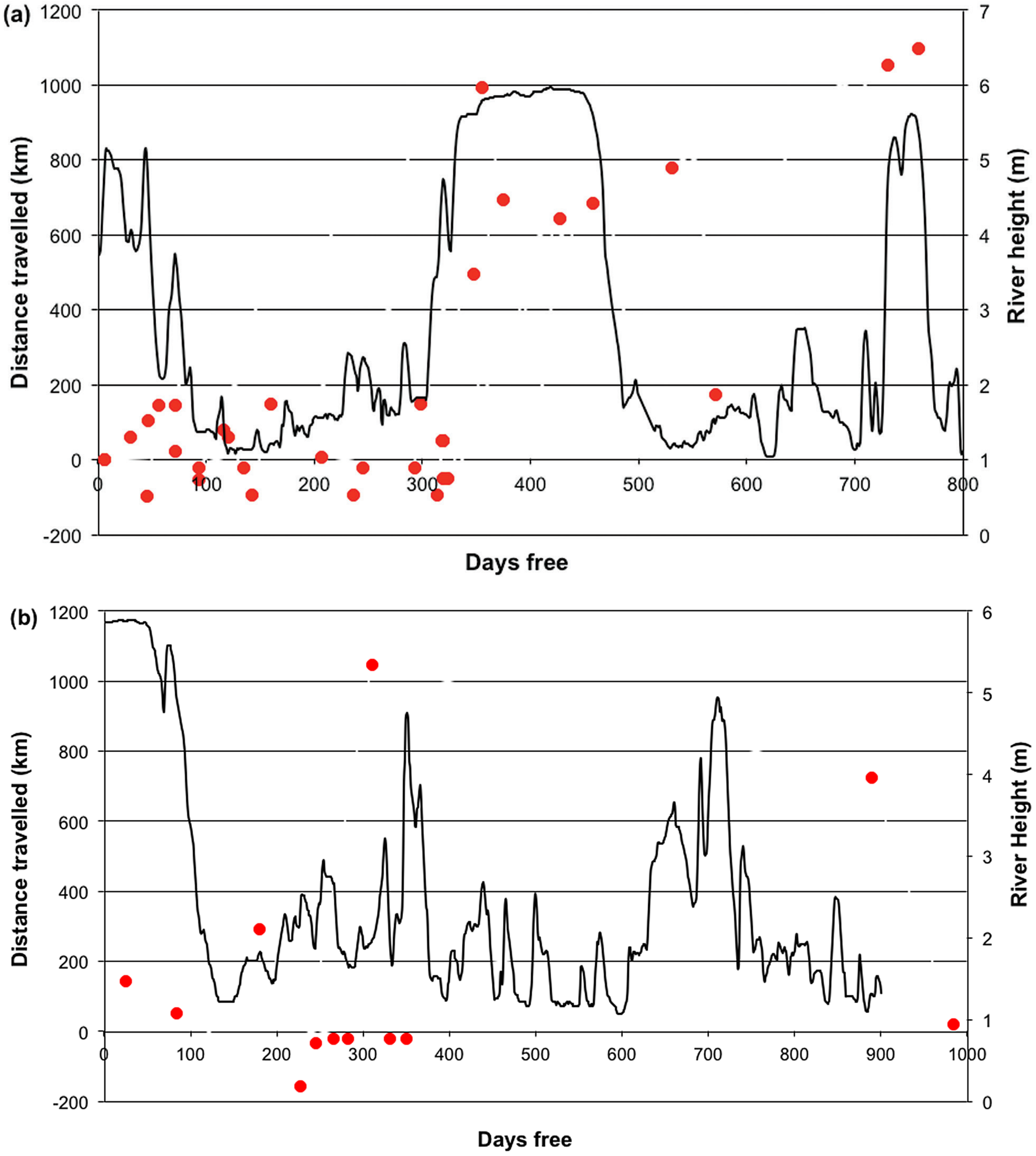


Figure 3. Distances travelled by recaptured *M. ambigua* upstream (positive values) and downstream (negative values) from Hattah, plotted against days free, that were tagged in **(a)** October 1963 (n=35), and **(b)** Sept to Nov 1960 (n=12). The daily River Heights for Barham on the Murray River are shown for these periods, supplied by Department of Environment, Climate Change and Water from the NSW Provisional Water Data. Overall total recaptured from Hattah tagging n=54.

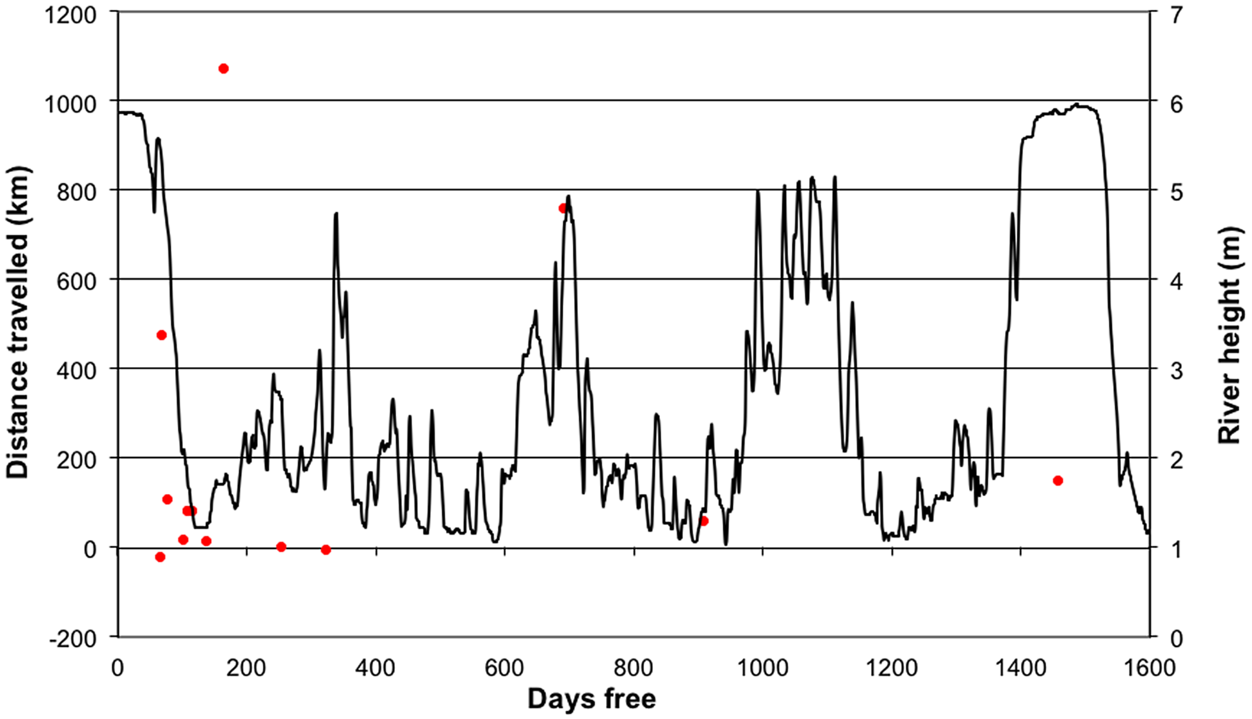


Figure 4. Distances travelled by recaptured *M. ambigua* upstream (positive values) and downstream (negative values) from Stoney Crossing plotted against days free, that were tagged in Sept 1960 (n=16). The daily River Heights for Barham on the Murray River are shown starting on 23 Sept 1960, supplied by Department of Environment , Climate Change and Water from the NSW Provisional Water Data. Overall total recaptured from Stoney Crossing tagging n=17.

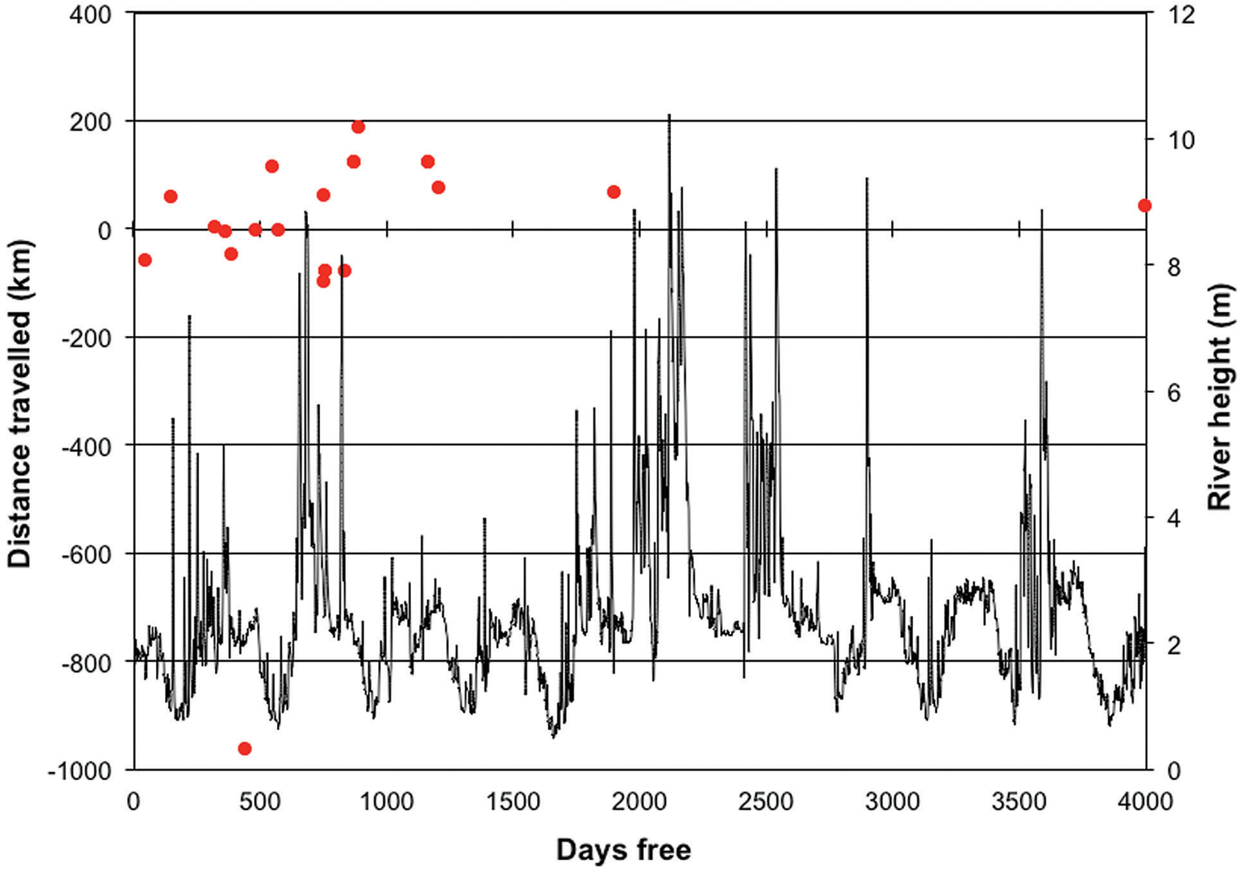


Figure 5. Distances travelled by recaptured *M. ambigua* upstream (positive values) and downstream (negative values) from Hay plotted against days free, that were tagged in Nov 1968 (n=22). The daily River Heights for Wagga Wagga on the Murrumbidgee River are shown starting on 17 Nov. 1968, supplied by Department of Environment, Climate Change and Water from the NSW Provisional Water Data. The six recaptures from the 1969 tagging have not been plotted. Overall total recaptured from Hay tagging n=28.

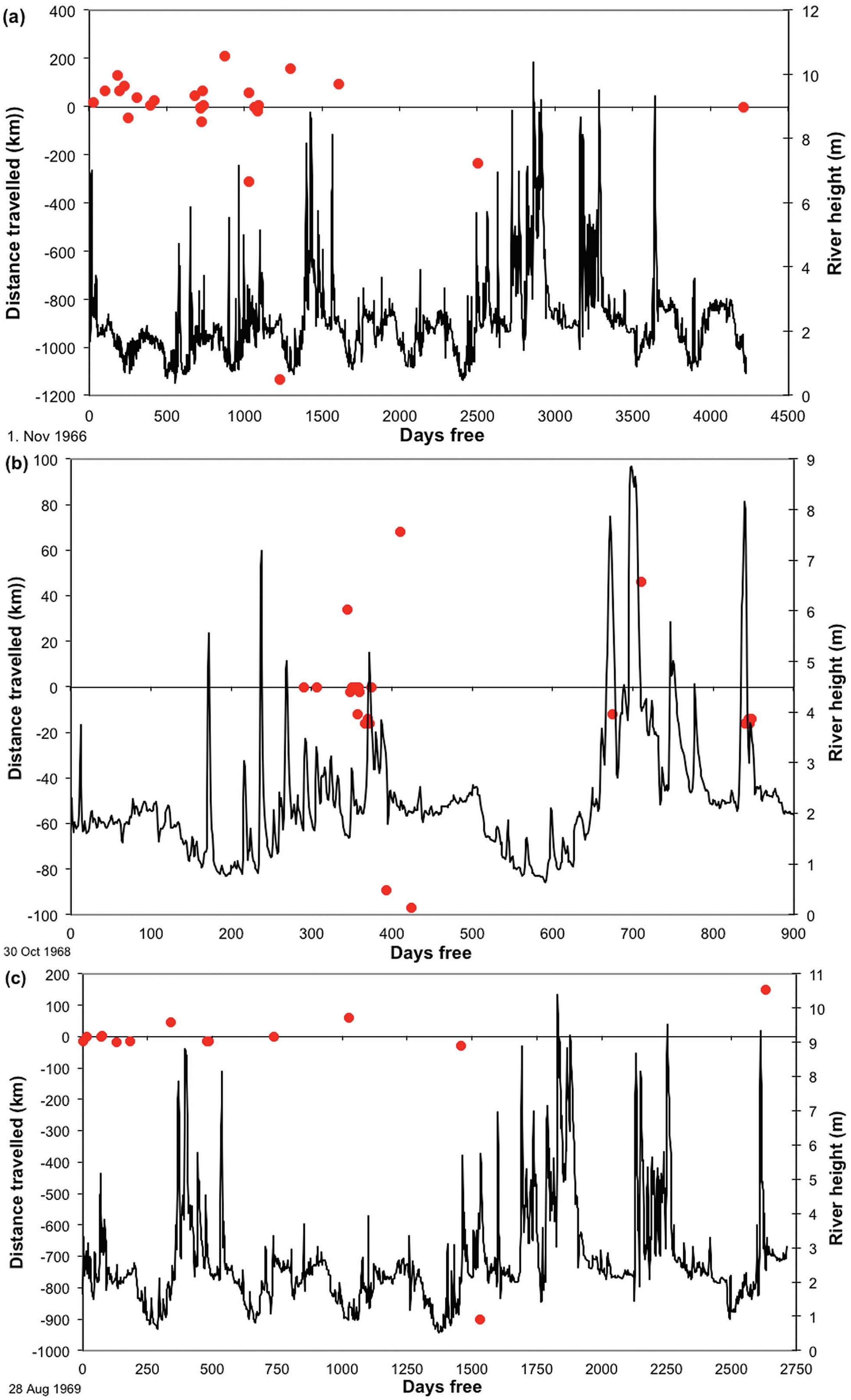


Figure 6. Distances travelled by recaptured *M. ambigua* upstream (positive values) and downstream (negative values) from Narrandera, plotted against days free, that were tagged in **(a)** Nov-Dec 1966 n=32, **(b)** Oct-Dec 1968 n=23, and **(c)** Aug –Dec 1969 n=14. The daily river heights for Wagga Wagga on the Murrumbidgee River are shown for these periods, supplied by Department of Environment, Climate Change and Water from the NSW Provisional Water Data.

only caught fish above 300mm in length because of the size mesh used. Scatter plots and correlation analysis indicated that there was a correlation between length of fish and distance travelled (up and down river combined) from the site of capture (mainly adult fish 309 to 563mm, mean 441.7mm) (Fig. 7a) (r=-0.206, n= 178, 0.005<P<0.01). The smaller fish (300-400mm) travelled further. When this is broken down into movement upstream and downstream, there was a strong correlation between size and upstream movement (Fig. 7b) (r=

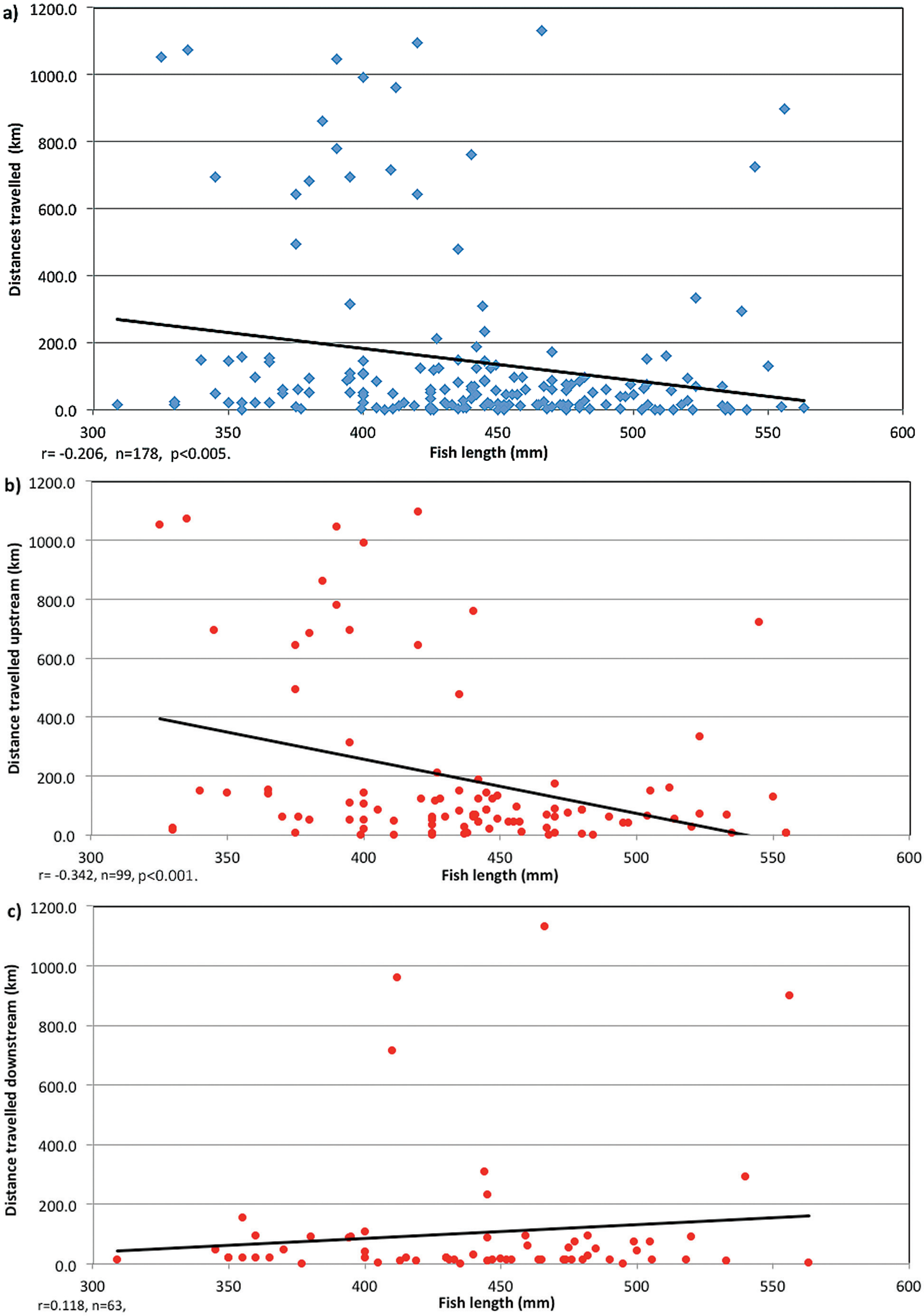


Figure 7. Distances travelled following tagging plotted against total length for each fish for all tagging sites. a) Up and downstream distances together. b) Upstream distances. c) Downstream distances. Sixteen zero movements were not plotted in separate up and downstream plots.

-0.342, n=99, P<0.001), again smaller fish moving further upstream, but no significant correlation between fish size with downstream movement (Fig. 7c).

Movement of 1167 of the 1243 *B. bidyanus* tagged were tagged at the Narrandera site (Table 1 and 3) and 18 fish were recaptured, sixteen of which were Narrandera tagged fish. Two of these were captured at the tagging site and two had moved a short distance upstream and four a short distance downstream < 60 km (Fig, 8). The remaining eight moved downstream, the furthest being nearly to Hay (Pevensey) (400 km) (Fig, 8). Two fish tagged at other sites were recaptured also. One had travelled 195 km upstream from Hay to Carathool, and one fish was collected in the Darling River at Brewarrina close to the site where it had been tagged two years earlier.

The fish that had moved the longest distance, 400 km, was free for 411 days. The fish that was free the longest, 4536 days, was recaptured only 32 km downstream. The fastest movements recorded for this species were 44 km upstream in 11 days and 48 km downstream in 5 days.

Movement of Sixty eight of the 84 M. *peelii peelii* tagged were tagged at Narrandera. Of the 17 fish recaptured 14 were Narrandera fish (Table 1 and 3). Six of the Narrandera fish were caught close to the point of initial tagging (Fig. 9). Three fish moved upstream, the furthest 141 km, and five moved downstream, the furthest 91 km. One fish captured and tagged 20 km west of Balranald at 11.6 kg in weight and 852 mm in length was recaptured at Gundagai, 1224 km upstream 488 days later at 14.1 kg in weight and 965 mm in length (Anon 1971 distances recalculated). This was also the fastest movement recorded at an average of 2.5 km/day. The longest period free for M. *peelii peelii* was 4431 days, although this fish had only moved 12 km downstream. Other recoveries were an upstream movement of 85 km from Hattah on the Murray River, and no movement in a fish recaptured at Brewarrina on the Darling River 333 days later.

There was no correlation between size of fish and distance travelled for M. *peelii peelii,* 3 kg or under, tagged at the Narrandera site. Seven travelled less than 20 km, 3 between 20 and 60 km and 4 between 80 and 140km. The two larger fish of 8.6 and 17.0 kg travelled 44 and 12 km respectively.

Discussion

Tagging and Recovery

Captures of fish were nil to poor in the Murrumbidgee River in 1967 and the Murray River in 1961 and 1962 when flood peaks were absent or minimal. As successful capture using drum nets is dependent on upstream movement of fish, this suggests that upstream movement during these periods was minimal.

In this program a total of 3392 fish were tagged and 218 (6.4%) were recovered. A similar tagging program was carried out by Reynolds (1983) in South Australia (SA) in which 14,333 (9674 were Carp, *Cyprinus carpio*) individuals were tagged and 1276 recovered

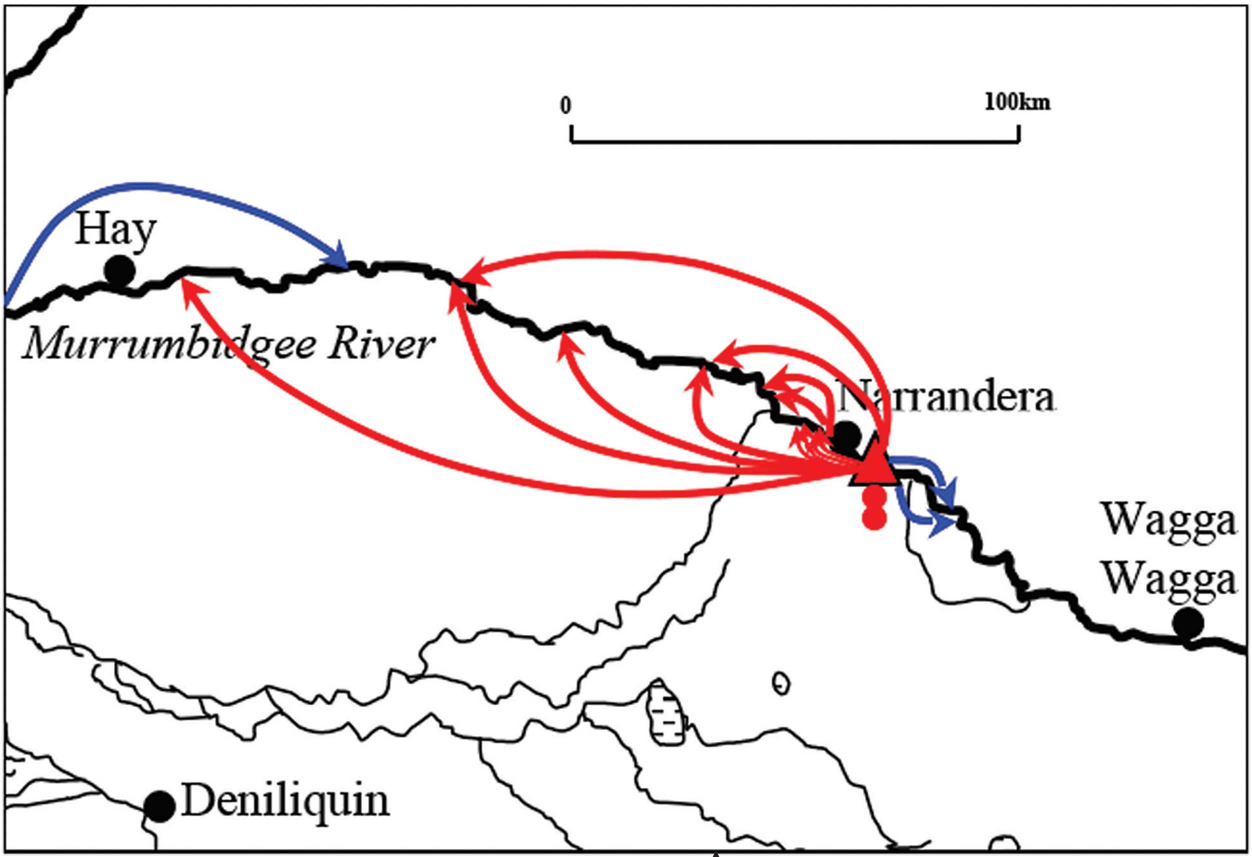


Figure 8. Movement of *Bidyanus bidyanus* mainly from Narrandera▲. Red arrows show downstream and blue arrows upstream movement. A single upstream movement was recorded from the Hay (Pevensey) site. Red dots indicate no movement.

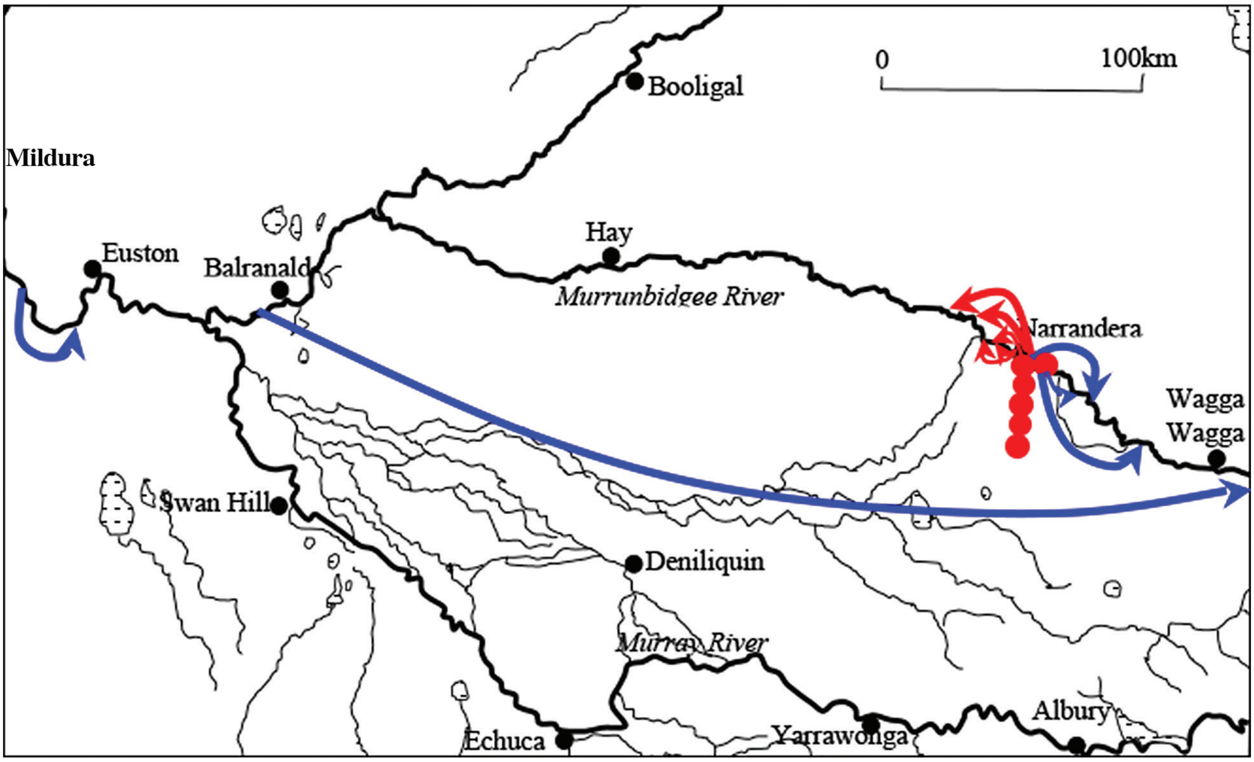


Figure 9. Movement of *M. peelii peelii.* Red arrows showing downstream and blue arrows upstream movement. Red dots indicate no movement from the site where they were first caught and tagged.

(8.9%). In the present study, confined to New South Wales waters, 2014 of the fish tagged were M. *ambigua* and 183 (9.1%) were recovered. In the SA program 3267 M. *ambigua* were tagged and 704 (21.5%) were recovered (Reynolds 1983).

The higher recapture rate of M. *ambigua* in this study in the Narrandera area (13.9%) (Table 2) probably reflects higher fishing pressure in this area even though considerable dispersion away from the tagging to recapture areas was evident. Reynolds (1983) recorded a higher recapture rate (21.5%) which could be a result of using external visible tags. Nevertheless because there was greater space on the IBT tags used in this study more usable information could be put on the tag to advise the angler what to do when he recaptured a tagged fish.

Mortality in this program exceeded 1.9% and may be attributed to either the catching or the tagging process. It is likely that mortality is higher than recorded as some affected fish may have been carried downstream away from the tagging area, and not recovered. The marked difference in mortality rates at different sites also may be a function of different temperatures at different sites, since fish are generally much more sensitive to fungal and bacterial infections at higher temperatures. Reynolds (1983) reported a tagging mortality level of 0.2%.

Movement ofM. ambigua is widely distributed in the Murray-Darling River System. It breeds in response to floods at temperatures above 23°C, and produces large numbers of pelagic eggs which hatch in about 33hr (Lake 1967b,c). Larvae start to swim and feed at around 5 days. These pelagic eggs and larvae could be carried up to 500 km downstream (Reynolds 1983) before becoming active swimmers. Upstream movement during some stage of their life cycle would appear to be critical, particularly in the lower reaches of the Murray River to prevent large numbers of eggs and larvae being flushed into saline waters thus jeopardising their survival, and to prevent a net downstream shift in the population. The marked net upstream movement of adult large fish from the lower two main tagging sites at Stoney Crossing and Hattah along with the findings of Reynolds (1983) support this assumption. The report by Mallen-Cooper et al. (1995) of significant numbers of juveniles (1 year old) moving upstream through Torrumbarry Weir, is consistent with this hypothesis.

The upstream movement at Hay is not so marked with a net movement showing more or less equal dispersion in each direction. Furthermore the net movement is downstream at Narrandera, the most eastern site, even though some significant upstream movement still occurs. No long distance upstream recoveries (over 211 km) were reported from Narrandera, but some long downstream recoveries up to 1131 km occurred (Table 4). Narrandera is closer to the eastern extremity of their range where water temperatures start to get cooler, possibly limiting further eastern movement. Even at Narrandera the upstream thrust during the breeding season is evident as indicated by the success of drum netting. This would appear to be important to active feeding at this time over freshly inundated ground and their movement into backwaters and billabongs, or streams and lakes which are critical to their general dispersal and breeding. Lake (1967a,b,c) indicated that recruitment to the population is dependent on floods and an increase in food supply, which stimulate breeding.

Most long distance movements were associated with spring floods. The catchability of fish using drum nets (Llewellyn 1968), and the recapture periodicity of long distance travellers (Fig. 5,6,8,9) tended to support this. Reynolds (1983) also concluded that upstream migrations of mature fish followed, and appeared to be triggered by, a rise in water level at the commencement of a major flood.

Analysis of distance moved by fish, as a function of fish length for fish between 309 and 563mm in this study, indicated that the larger fish moved less than smaller fish (Fig. 7a), and that the larger fish moved upstream less while the downstream movement of large fish was not significantly different from small fish (Fig. 7b,c). This contrasts with the findings of Reynolds (1983) who suggested that movement patterns were length specific with large mature fish being more likely to move upstream for greater distances. However in Reynolds study mean fish lengths at his two sites were 310 and 345 mm, while in this study the mean length of recaptured fish at tagging was 443 mm (range 309 – 563 mm which included mainly mature adults). It is therefore possible that the larger sized fish caught in this study could account for these differences. These results should be interpreted with caution. Smaller adult fish have a larger length to weight ratio than larger fish (Llewellyn 2008; 2011) and may have more thrust against river flows and therefore may have the capacity to travel further. Older larger fish may be more likely to remain in deep holes or billabongs and not move out into shallower fast running water.

The development of acoustic and radio tagging enabling continuous or intermittent recording of individual fish has confirmed that movement is generally stimulated by increasing river flows and water temperatures and that some long distance movements occur (O'Connor *et al.* 2005; Koster *et al.* 2012; Crook and Koster 2004; Koehn *et al.* 2004) . They also found that these movements are generally associated with breeding. Connectivity and movement of populations between river systems were demonstrated by Koster *et al.* (2012) in the Goulburn and Murray Rivers as was indicated in this study with fish moving from the Murray to Darling Rivers and Murrumbidgee to Murray Rivers. Radio tagging techniques demonstrated G. *ambigua* had strong home range fidelity even after moving considerable distances (O'Connor *et al.* 2005), a feature not ascertained using methods in this study. He also found they did not move much during winter or low flow periods. Leigh and Zampatti (2011) postulated that 100km of river was needed for M. *ambigua* connectivity and movement for successful breeding, though this was not necessary when successful pond breeding was carried out at the Inland Fisheries Research Station, Narrandera (Lake 1967 b, c). Recent research has indicated the importance of downstream movement in M. *ambigua* populations (Koehn *et al.* 2004), which although demonstrated in earlier studies had not received adequate attention.

Movement of Little information is available on the movement of *B. bidyanus*, apart from that reported by Reynolds (1983). He indicated that for *B. bidyanus* (289mm mean length) 73% underwent movements greater than10km, similar to M. *ambigua*, but with equal movement up and downstream unlike M. *ambigua*, and that the greatest distance moved was 570km upstream. However it has been seen frequently schooling at weirs, traversing fish ladders and is reported by many (eg Merrick and Schmida 1984) as undergoing extensive spawning migrations. Extensive upstream movement during spring floods appears to occur, evidenced by the large catches at Narrandera caught in drum nets which rely on upstream movement. Poor to nil catches of this species occur using this method for much of the rest of the year (Llewellyn 1968). As breeding of *B. bidyanus* is similar to M. *ambigua*, with planktonic ova and larvae, it is logical to expect similar patterns of migration. This study showed there was a marked movement of *B. bidyanus* downstream from Narrandera in the east (Fig, 8), and a single upstream movement from a fish tagged at Hay (Fig.8), unlike Reynolds (1983) findings in the lower Murray. Overall, the results of this study and of Reynolds (1983) indicate that upstream movements occur in the lower Murray River at times, but an overall downstream movement occurs in the Murrumbidgee River at Narrandera, similar to what was found in M. *ambigua*. However the recapture rate for this species was poor being only 1.9% in the South Australian study (Reynolds 1983) and 1.4% in this study.

Movement of The different movement patterns in this percichthyid can be related to the different biology- as discussed below. The recapture data for M. *peelii peelii* suggests that some smaller fish below 3 kg may disperse from their natal area up and downstream for distances of up to 140 km, although there is no evidence for substantial movement during floods as occurred in M. *ambigua* and *B. bidyanus*. This type of general dispersal of young fish would be expected for a large fish that attaches its ova in a cluster to solid objects and has young that are only likely to be displaced relatively small distances downstream after hatching. However Jones and Stuart (2007) found that juvenile Murray Cod had an average daily movement of only 15 ±55m (n=8). Humphries and King (2003) and Humphries (2005) classified the larvae of *M. peelii peelii* as obligate drifters, and estimated that their total drift downstream was about 20-28 km occurring over 5-7 days at a rate of about 4km per day, moving only at night. Although reported movements in this species seem to be limited, the significant movement of the one fish in this study indicates that long distances can be travelled. This fish travelled 1224 km (760miles)(recalculated from Anon 1971), which is the longest distance recorded in the literature, to my knowledge. Roughley (1961) recorded tagged M. *peelii peelii* moving from Bringagee to Narrandera, "150 miles upstream" over varying lengths of time. Similarly, Simpson and Mapleton (2002), who used radio-telemetry to track *Maccullochella peelii mariensis* in the Mary River, found that fish displayed two different types of movement, rapid directional long distance movement and local non directional movement within their home range. However maximum distances travelled in this sub species were much smaller. Leigh and Zampatti (2011) indicated that no clear pattern of emigration was found for Murray Cod and that they bred without any need for high river flows. Radio tracking enables preferred habitats to be determined, which was not possible using techniques in this study. Jones and Stuart (2007) and Koehn (2009) found they used the mainstream channel habitats with heavy loadings of woody material, and Jones and Stuart (2007) also indicated they frequented stream depths around 2.3m and flows around 0.56m.s^{-1}. The continual or intermittent monitoring of individual fish using radio tags also enables the examination of how or when fish navigate obstructions particularly weirs (Koehn *et al*. 2004), (See Plate 5a weir in flood Plate, 5b weir in low flow), which is so important in facilitating the free movement and mixing of fish populations throughout the Murray Darling System.

Conclusions.

This study reports movements of three species of fish in the mid Murray and mid and lower reaches of the Murrumbidgee Rivers. It indicates that most movements are less than 200 km but occasional fish move much longer distances. These movements are particularly important to ensure mixing of populations and to compensate for downstream movement of planktonic stages. In an arid environment where lagoons and sections of river can dry up giving rise to significant fish kills, dispersion of fish from waterholes where fish still survive is critically important for repopulation of affected areas. Movement of *M. ambigua* and *B. bidyanus* within the Murray-Darling River System seems to indicate a greater upstream movement from the lower reaches and a greater downstream movement from the upper reaches where one approaches the limits of their distribution. *M. peelii peelii* were generally fairly sedentary with only occasional long distant movements.

Acknowledgements

I would like to thank New South Wales State Fisheries (now Department of Trade and Investment , Regional Structure and Services , NSW Department of Primary Industries, Fisheries NSW) for permission to do this work originally and the Victorian Fisheries and Wildlife Department (now Department of Environment and Primary Industries, Fisheries) and their field staff for tagging some of the *M. ambigua*. Valuable assistance was given by Mr D.M. Smith, and the late Mr F. Atkinson in the field, and the late Mrs M. Walton in the field and laboratory. Data on river heights was provided by the Department of Environment, Climate Change and Water from the NSW Provisional Water Data. I also wish to thank Dr G. Courtice for reading the manuscript and providing helpful comments.

References

Anon, 1971. Murray Cod takes long distance title. *Fisherman. Journal of State Fisheries of New South Wales:* **4(2)** Spring 1971: 24

Battaglene, S.C. 1991. *The Golden Perch,* Macquaria ambigua *(Pisces: Percichthyidae) of Lake Keepit.* M. Sc. Thesis, University of New South Wales.

Battaglene, S.C. and Callanan, M D. 1991. *Lake Keepit fish study***.** Final Report to the New South Wales Department of Water Resources, Sydney.

Crook, D. and Koster, W. 2004. Assemblage structure of fish and acoustic tracking in the lower Goulburn River. Report Arthur Rylah Institute of Environmental Research, Heidelberg, Victoria. (2.p).

Humphries, P. 2005. Spawning time and early life history of Murray Cod, *Maccullochella peelii peelii* (Mitchell) in an Australian river. *Environmental Biology of Fishes***. 72(4):** 393-407.

Humphries, P. and King, A.J. 2003. *Drifting fish larvae in Murray-Darling Basin rivers: composition, spatial and temporal patterns and distance drifted*. Canberra workshop June 2003.

Jones, M.J. and Stuart, I.G. 2007. Movements and habitat use of common carp (*Cyprinus carpio*) and Murray cod (*Maccullochella peelii peelii*) juveniles in a large lowland Australian river. *Ecology of Freshwater Fishes* **16(2)**: 210-20. June 2007.

Koehn, J.D. 2009. Multi-scale habitat selection by Murray cod *Maccullochella peelii peelii* in two lowland rivers. *Journal of Fish Biology* **75**: 113–29. doi: 10.1111/j.1095-8649.2009.02270.x.

Koehn, J. Stuart, I. and **Crook, D. 2004.** Linking the ecological importance of downstream fish movements to management of Murray-Darling Basin fish populations. Pp. 67-78. *In:* Lintermans, M. and Phillips, B. (eds.) *Downstream Movement of Fish in the Murray-Darling Basin.- Statement, recommendations and supporting papers*. Workshop held in Canberra, 3-4 June 2003: Murray-Darling Basin Commission, Canberra.

Koster, W. Crook, D. and Dawson, D. 2012. Movement and connectivity in populations of adult Golden perch *Macquaria ambigua* in the Goulburn and Murray Rivers, Australia. *Australian Society for Limnology Congress 2012*, Session Life History and Population Ecology.

Lake, J.S. 1967a. Freshwater Fish of the Murray - Darling River System. *Research Bulletin New South Wales Fisheries,* **7**:1-48.

Lake, J.S. 1967b. Rearing experiments with five species of Australian freshwater fishes, I. Inducement to spawning. *Australian Journal of Marine and Freshwater Research* **18**:137-53.

Lake, J.S. 1967c. Rearing experiments with five species of Australian freshwater fishes, II. Morphogenesis and ontogeny. *Australian Journal of Marine and Freshwater Research* **18**:155-73.

Leigh,S.J. and Zampatti, B.P. 2011. Movement and spawning of Murray cod (*Maccullochella peelii*) and golden perch (*Macquaria ambigua ambigua*) in response to a small scale flow manipulation in the Chowilla Anabranch system. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. Publication No. F2011/000646-1, *SARDI Research Report Series* **No.536**. June 2011.

Llewellyn, L.C. 1968. Tagging gives answers to fish growth queries. *Fisherman. Journal of State Fisheries, New South Wales* **3 (1)**: 1-4.

Llewellyn, L.C. 2008. Estimation of growth of the Golden Perch *Macquaria ambigua* based on a tagging program between 1959 and 1970. *Australian Zoologist* **34 (4)**: 522-9.

Llewellyn, L. C. 2011. Length - weight relationships of freshwater fish from the Murray-Darling River System in inland New South Wales, with particular reference to the Golden Perch *Macquaria ambigua*. *Australian Zoologist* **35(3),** 435-57.

Mallen - Cooper, M 1994. Swimming ability of adult Golden Perch, *Macquaria ambigua* (Percichthyidae), and adult Silver Perch, *Bidyanus bidyanus* (Teraponidae), in an experimental vertical slot fishway. *Australian Journal of Marine and Freshwater Research* **45**:191-8.

Mallen - Cooper, M., Stuart, I.G., Hides-Pearson, F. and Harris, J.H. 1995. *Fish migration in the Murray River and assessment of the Torrumbarry fishway*. New South Wales Fisheries Research Institute, Cronulla and the Cooperative Research Centre for Freshwater Ecology, Canberra. Final report for the Natural Resource Management Strategy Project N002.

Merrick, J.R. and Schmida, G.E. 1984. *Australian Freshwater Fish, Biology and Management*. Griffin Press Limited, Netley, SA.

O'Connor, J., O'Mahony, D. and O'Mahony, J. 2003. *Downstream movement of adult Murray Darling fish species.* Arthur Rylah Institute for Environmental Research. Heidelberg, Victoria. Final Report to Agriculture Fisheries and Forestry Australia, Canberra.

O'Connor, J.P., O'Mahony, D.J. and O'Mahony, J.M. 2005. Movements of *Macquaria ambigua*, in the Murray River, south-eastern Australia. *Journal of Fish Biology* **66(2)**:392-403.

Pusey, B.J., Kennard, M.J. and Arthington, A.H. 2004. *Freshwater Fishes of North-eastern Australia.* CSIRO Publishing, Collingwood.

Reynolds, L.F. 1976. Tagging important in river Murray fish study. *Australian Fisheries* **35 (7) July**: 4-6 and 22.

Reynolds, L.F. 1983. Migration patterns of five fish species in the Murray-Darling River system. *Australian Journal of Marine and Freshwater Research* **34**: 857-7.

Roughley, T.C. 1961. *Fish and Fisheries of Australia*. Angus and Robertson, Sydney, NSW.

Simpson, R.R. and Mapleton, A.J. 2002. Movements and habitat use by the endangered Australian freshwater Mary River Cod, *Maccullochella peelii mariensis*. *Environmental Biology of Fishes* **65**:401-10.

APPENDIX I

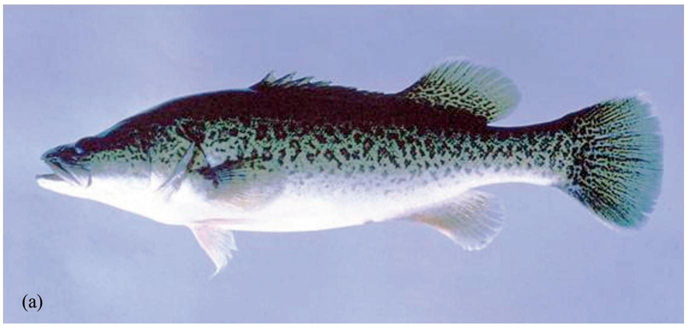
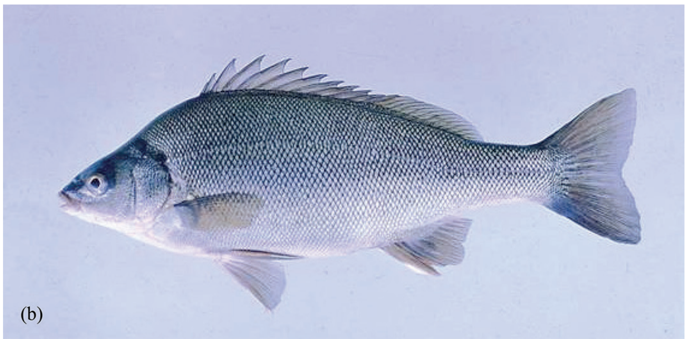
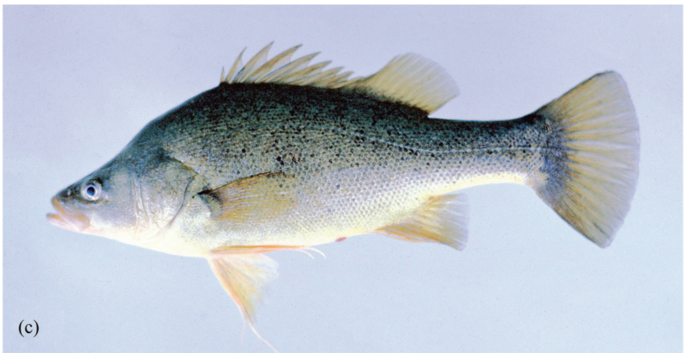


Plate 1. a) Murray Cod (*Maccullochella peelii peelii*)



b) Silver Perch (*Bidyanus bidyanus*)



c) Golden Perch (*Macquaria ambigua*).

Plate 2. a) Freshwater Catfish (*Tandanus tandanus*)

b) Redfin (*Perca fluviatilis*)

c) Tench (*Tinca tinca*).

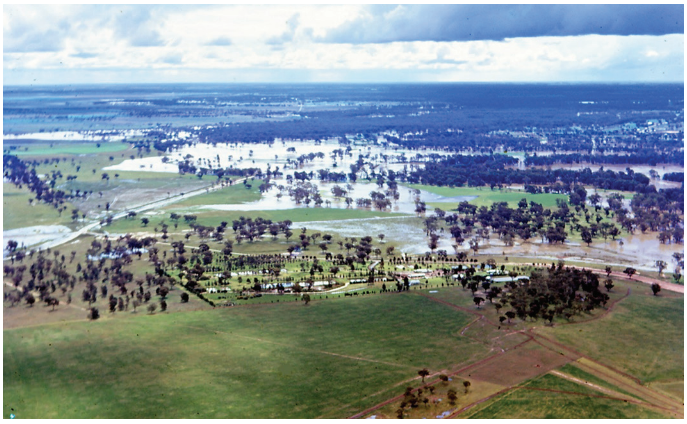


Plate 3. a) Murrumbidgee River in flood with Inland Fisheries Research Station (IFRS) in centre looking west.

b) IFRS looking east up front drive.

APPENDIX I

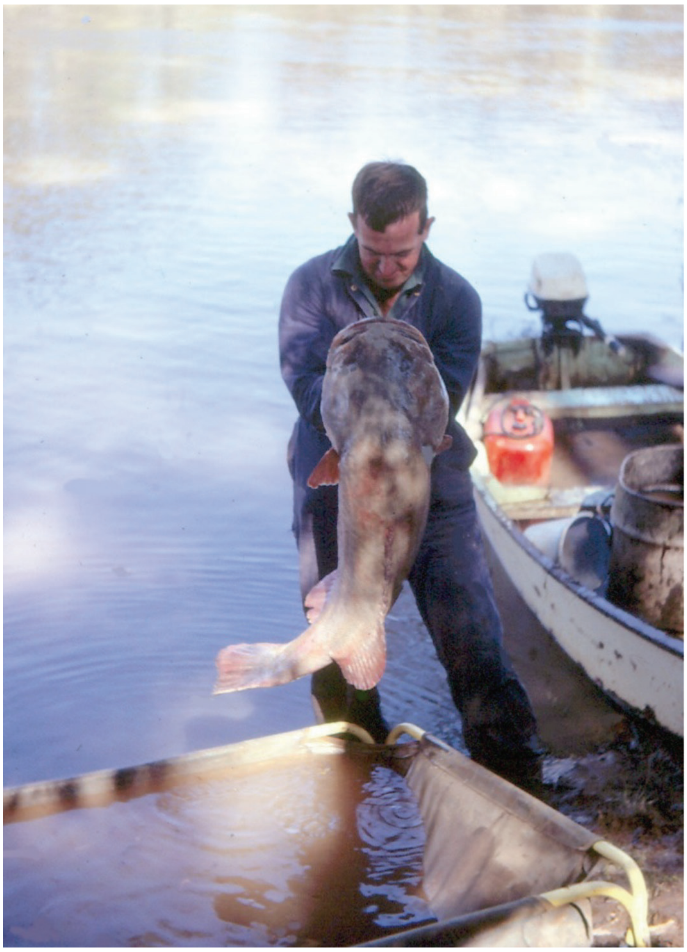


Plate 4. Jo Smith transferring Murray Cod from carrying drum on the boat to the anaesthetizing pool.

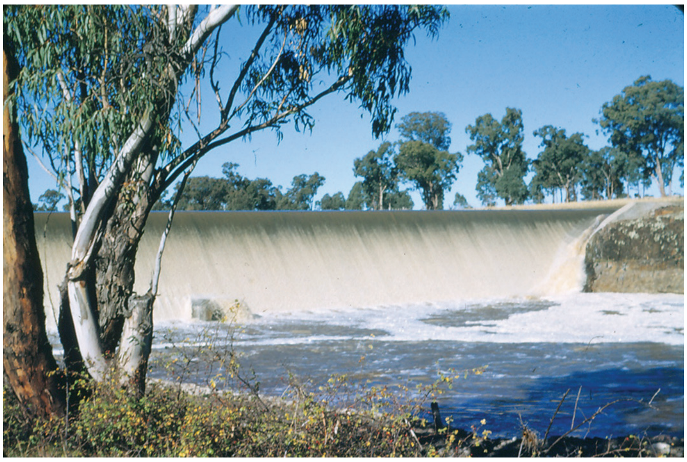
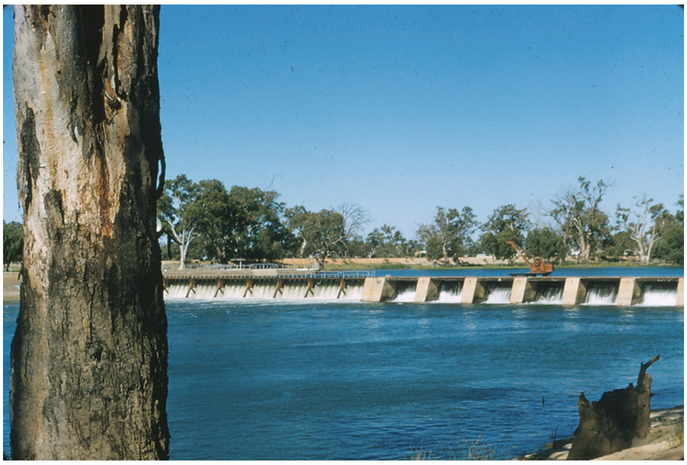


Plate 5. Weirs in the Murray Darling a) under high flow



b) under low flow.